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Publication Title:

Field emission structure and method of forming the same

Abstract:

A process for making a tip microstructure (22) in amorphous silicon or polysilicon (12). A layer of nitride is first deposited on the amorphous silicon or polysilicon (12). Then the amorphous silicon or polysilicon (12) is roughly patterned to form the base (24) of the tip structure (22). The tip is carved out of the amorphous silicon or polysilicon (12) by using an oxide growth process that is controlled by the amount of dopant in the amorphous silicon or polysilicon (12). After the tip is carved, the oxide is stripped away exposing the tip (26).

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(54) Field emission structure and method of forming the same.

(57) A process for making a tip microstructure (22) in amorphous silicon or polysilicon (12). A layer of nitride is first deposited on the amorphous silicon or polysilicon (12). Then the amorphous silicon or polysilicon (12) is roughly patterned to form the base (24) of the tip structure (22). The tip is carved out of the amorphous silicon or polysilicon (12) by using an oxide growth process that is controlled by the amount of dopant in the amorphous silicon or polysilicon (12). After the tip is carved, the oxide is stripped away exposing the tip (26).

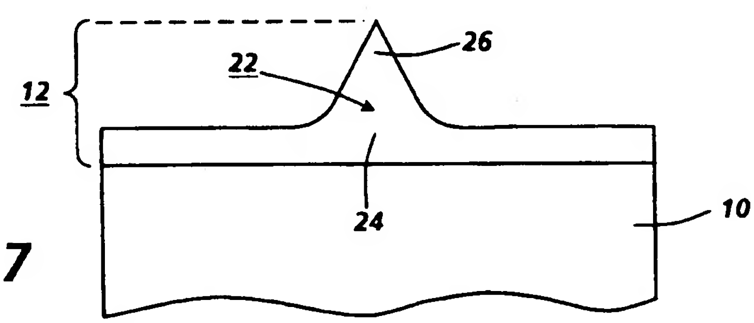

FIG. 7

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This invention relates generally to field emission structures, such as those used in vacuum microelectronic devices and more particularly concerns fabrication methods for making the field emission structure

Field emission structures have been used in a variety of devices including including vacuum micro tubes (W.J. Orvis et al "Modeling and Fabricating Micro-Cavity Integrated Vacuum Tubes", IEEE Transactions on Electron Devices, Vol. 36. no. 11. November 1989). These elements can be made in a variety of ways. In a paper by Yao, Arney, and MacDonald in the Journal of Microelectromechanical systems, vol. 1, no. 1, March 1992 titled Fabrication of High Frequency Two-Dimensional Nanoactuators for Scanned Probe Devices a two-dimensional field emission structure is made by following the process steps of:

A) depositing an oxide-nitride-oxide stack on a substrate and an aluminum mask on the stack,

B) etching the stack and the substrate to form a protruding structure,

C) depositing a sidewall mask on the protruding structure,

D)performing an isotropic recess etch to form an undercut structure in the protruding structure and to start forming the field emission structure,

E) performing an isolation oxidation to finish forming the field emission structure,

F) removing the oxidation to release the structure.

This process results in a pair of conical tips that can be used in scanned probe devices This process is cumbersome because it uses many complex steps to form the pair of complex tips and because some of the steps, such as the isotropic recess etch are difficult to control and reproduce with accuracy.

Briefly stated and in accordance with the present invention, there is provided a process for making tip structures according to claim 1 of the appended claims.

A substrate is prepared with a structural layer of a material that may be oxidized. It is important that the oxidation rate of the material be controllable. In the example to be given, the oxidation rate is controlled by doping the material with specific impurities. The concentrations of the impurities determine the rate of oxidation.

The structural layer is patterned into a rough column or rail to locate the rough shape of the final tip structure. Once rough patterning has been accomplished, the oxide bumpers are grown on the structural layer by oxidizing the structural layer. The oxidation rate is controlled by the impurity levels so that the top portion of the column oxidizes much faster than the lower portions of the column. Therefore, the top portion will be oxidized much faster than the lower portions After a determinable period of time, the top of the column will be nearly completely oxidized while the lower portions will be comparatively unoxidized. The unoxidized portions at the top of the column will come to a sharp point or tip. The larger unoxidized portion underneath the point will form a base or support for the tip.

The remaining step is to remove the oxide bumpers to expose the unoxidized tip.

In a variation of this procedure opposed tip pairs may be produced. A substrate is again prepared with a structural layer of a material that may be oxidized. The structural layer is patterned into a rough column or rail to locate the rough shape of the final opposed tip pair structure. Once rough patterning has been accomplished the structural layer is oxidized. The oxidation rate is controlled by the impurity levels so that the middle portion of the column oxidizes much faster than either the lower or upper portions of the column. Therefore the middle portion will be oxidized much faster than either the upper or the lower portions. After a determinable portion of time, the middle of the column will be completely oxidized while the upper and lower portions are still comparatively unoxidized. The unoxidized portions around the middle of the column will come to two sharp points or tips. The larger unoxidized portions on either side of the points will form bases or supports for the tips. As before, the final step is to remove the oxidation to expose the unoxidized tips.

The process preferably comprises the additional steps of implanting a dopant, and diffusion of the dopant into said wall means to provide said concentration gradient of bumper growth controlling means.

Preferably, the wall means comprises a layer of polysilicon covered with a layer of nitride, said surface spaced from said generally planar surface being said layer of nitride.

Preferably, the structural layer comprises a layer of amorphous silicon covered with a layer of nitride, said surface spaced from said generally planar surface being said layer of nitride.

Embodiments of the present inventin will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a cross-section of a substrate after deposition of a structural layer of amorphous silicon or polysilicon,

Figure 2 is a graph describing the dopant concentration in the structural layer of amorphous silicon or polysilicon shown in **Figure 1**,

Figure 3 is a cross-section of the substrate shown in **Figure 1** after nitride deposition,

Figure 4 is a cross-section of the substrate shown in **Figure 3** after photoresist patterning,

Figure 5 is a cross-section of the substrate shown in **Figure 4** after patterning the structural layer of amorphous silicon or polysilicon,

Figure 6 is a cross-section of the substrate shown in **Figure 5** after oxidation,

Figure 7 is a cross-section of the substrate shown in **Figure 6** after oxide removal exposing the tip structure,

Figure 8 is a cross-section of a substrate after deposition of a structural layer of amorphous silicon or polysilicon,

Figure 9 is a graph describing the dopant concentration in the structural layer of amorphous silicon or polysilicon shown in **Figure 8**,

Figure 10 is a cross-section of the substrate shown in **Figure 8** after nitride deposition,

Figure 11 is a cross-section of the substrate shown in **Figure 10** after photoresist patterning,

Figure 12 is a cross-section of the substrate shown in **Figure 11** after patterning the structural layer of amorphous silicon or polysilicon,

Figure 13 is a cross-section of the substrate shown in **Figure 12** after oxidation,

Figure 14 is a cross-section of the substrate shown in **Figure 13** after photoresist deposition,

Figure 15 is a cross-section of the substrate shown in **Figure 14** after photoresist patterning,

Figure 16 is a cross-section of the substrate shown in **Figure 15** after metal deposition,

Figure 17 is a cross-section of the substrate shown in **Figure 16** after photoresist and oxide removal.

The structure is produced on a substrate **10** as shown in figure **1**. While silicon is convenient for the substrate **10** it is not necessary for the process. A 1.5 - 2.0 µm layer of amorphous silicon or polysilicon **12** with a surface **11** is deposited on the substrate **10**. The amorphous silicon or polysilicon **12** will have a dopant concentration profile **14**, as shown in figures **1** and **2**, that is highest at the surface **11** of the amorphous silicon or polysilicon **12**. The dopant concentration will be the least at the amorphous silicon or polysilicon **12** interface **13** with the substrate **10**. This dopant concentration can be accomplished in several ways, either by in situ doping or by ion implantation followed by diffusing. Both of these processes are well known and standard in the art.

In figure **3**, a nitride layer **16**, 0.3 - 0.4 µm thick, has been deposited on the amorphous silicon or polysilicon **12**. If it is desired to produce the dopant concentration profile **14** by ion implantation and annealing rather than by in situ doping the ion implantation and annealing steps may be done before the deposition of the nitride layer **16**.

As shown in figure **4** the next step is to pattern the nitride layer **16** and the amorphous silicon or polysilicon **12** by conventional photoresist processes. Figure **5**, shows the nitride layer **16**, and the amorphous silicon or polysilicon **12** etched using conventional dry etching techniques. The amorphous silicon or polysilicon **12** will have tapered sidewalls due to the dopant concentration profile **14** in the amorphous silicon or polysilicon layer **12**. The larger dopant concentration speeds up the etching process.

The amorphous silicon or polysilicon **12** is then oxidized to grow oxide bumpers **20** as shown in figure **6**. The growth and control of oxide bumpers is discussed in US-A-4,400,866 and US-A-4,375,643 by Bol and Keming. The oxide bumpers will grow faster where the dopant concentration is the largest. Referring back to figures **1** and **2**, the dopant concentration is the largest at the surface **11** of the amorphous silicon or polysilicon **12**. The oxide bumper **20** will grow fastest and thickest near the surface **11** of the amorphous silicon or polysilicon **12** . The nitride layer **16** on the surface **11** of the amorphous silicon or polysilicon **12** will contribute to the shape of the oxide bumper **20**. Since oxygen does not oxidize nitride, no oxide will be grown on the nitride layer **16**. The ability of oxygen to oxidize the amorphous silicon or polysilicon **12** will be reduced at the amorphous silicon or polysilicon 12 and nitride layer 16 interface 13 since the oxygen will have a reduced ability to diffuse along that interface due to protection of amorphous silicon or polysilicon 12 by the nitride layer 16. This phenomenon is very similar to the one responsible for the Bird's Beak formation in the CMOS or NMOS LOCOS processes. The oxidation rates will be fastest somewhat below the interface 13 and decrease with the decreasing dopant concentration.

As the oxide bumper **20** grows, the remaining amorphous silicon or polysilicon **12** will form a tip structure **22** including the base **24** and the sharp point **26**. The oxide bumper **20** and the amorphous silicon or polysilicon **12** will form a partial or pseudo parabolic relationship in the example shown. Since oxidation rates are well known and easily controllable, the size and shape of the tip structure **22** can be precisely controlled.

The final step, as shown in figure **7** is removal of the oxide and nitride layers by well known conventional process steps leaving the fully formed tip structure **22** exposed.

The above process sequence described the steps necessary to produce a single tip. A slight modification of the process steps will produce opposing tip pairs. In the following sequence for opposing tip pairs, like structures will use the same numbers but with an "a" appended to indicate that they belong to the opposed tip pair sequence.

Again, the structure is produced on a substrate **10a** as shown in figure **8**. While silicon is convenient for the substrate **10a** it is not necessary for the process. A layer of amorphous silicon or polysilicon **12a**, with a surface **11a**, is deposited on the substrate **10a**. The amorphous silicon or polysilicon **12a** will have a dopant concentration profile **14a**, as shown in figures **8** and **9**, that is highest near the middle of the amorphous silicon or polysilicon **12a**. The dopant concentration will be the least at the amorphous silicon or polysilicon **12** interface **13** with the substrate **10a** and

at the surface 11a of the amorphous silicon or polysilicon 12a. This dopant concentration can be accomplished in several ways, either by in situ doping or by ion implantation followed by annealing Both of these processes are well known and standard in the art.

In figure 10, a nitride layer 16a has been deposited on the amorphous silicon or polysilicon 12a. If it is desired to produce the dopant concentration profile 14a by ion implantation and annealing rather, than by in situ doping, the ion implantation and annealing steps may be done before the deposition of the nitride layer 16a.

As shown in figure 11 the next step is to pattern layers 16 and 12 by conventional photoresist process. Figure 12, shows the nitride layer 16, and the amorphous silicon or polysilicon 12 etched using conventional dry etching techniques. The amorphous silicon or polysilicon 12a will have slightly concave sidewalls due to the dopant concentration profile 14a in the amorphous silicon or polysilicon 12a. The larger dopant concentration speeds up the etching process.

The amorphous silicon or polysilicon 12a is then oxidized as shown in figure 13. The oxide bumpers will grow faster where the dopant concentration is the largest. Referring to figures 8 and 9, the dopant concentration is the largest near the middle of the amorphous silicon or polysilicon 12a. The oxide bumper 20a will grow fastest and thickest near the middle of the amorphous silicon or polysilicon 12a. The oxidation rates will be fastest near the middle of the amorphous silicon or polysilicon 12 and decrease with the decreasing dopant concentration. As the oxide grows, the remaining unoxidized amorphous silicon or polysilicon 12a will form a dual opposed tip structure 22a with two bases 24a and two sharp points 26a. The oxide bumper 20a and the amorphous silicon or polysilicon 12a will form a partial or pseudo hyperbolic relationship. Since oxidation rates are well known and easily controllable, the size and shape of the dual opposed tip structure 22a can be precisely controlled.

As shown in figure 14, a layer of planarizing photoresist 28 is spun on the exposed surfaces. This is done to provide a method for attaching the upper tip to a lever arm. In figure 15, the photoresist 28 is etched to reveal the nitride layer 16 on the base 24a of the upper tip. Then as shown in figure 16, first the nitride layer 16 is removed and a layer of metal 30 or other material is deposited on the surface of the photoresist 28 and the base 26a of the upper tip.

Once the metal 30 is patterned in any conventional manner to be attached to other portions of the substrate, oxide, or other structures present on the substrate the photoresist 28 and the oxide bumper 22a can be removed to expose the opposed tip pair 22a as is shown in figure 17.

Claims

1. A process for making a tip comprising;
   a. providing a structural member having wall means extending from a generally planar surface with said wall means having a surface spaced from and generally parallel to the generally planar surface, said wall means having a concentration gradient of bumper growth controlling material such that a portion of said wall means located between said surfaces has a higher concentration of the bumper growth controlling material than the rest of said wall means,
   b. growing bumper means into said wall means to convert said wall means into said bumper means with complete conversion occurring at said portion with the higher concentration of bumper growth controlling material and less than complete conversion occurring at the rest of said wall means to form at least one tapered tip on the non-converted portion of said wall means, and
   c. removing said wall means from said wall means such that the tapered tip is exposed.

2. The process in claim 1 wherein said wall means prior to growing said bumper means is cylindrical and said resulting tip is conical.

3. The process in claim 1 wherein said wall means prior to growing said bumper means is multi-sided and said resulting tip is a multi-sided pyramid.

4. The process in claim 1 wherein said wall means prior to growing said bumper means is elongated and said resulting tip is a rail.

5. The process in any of claims 1 to 4 wherein the heavily concentrated portion is located near said surface spaced from said generally planar surface of said wall means.

6. The process in any of the preceding claims wherein said bumper means comprises an oxide.

7. The process in any of the preceding claims wherein said bumper growth controlling means is a dopant.

8. The process in any of the preceding claims wherein the completely converted portion is located such that there is a non-converted portion between the completely converted portion and the surface spaced from said generally planar surface and another non-converted portion between the completely converted portion and the generally planar surface to form two opposed

tips.

9. The process in claim 8 wherein said surface spaced from said generally planar surface is nitride.

10. The process in any of the preceding claims comprising the additional steps of in situ doping of a dopant into said wall means to provide said concentration gradient of bumper growth controlling means.

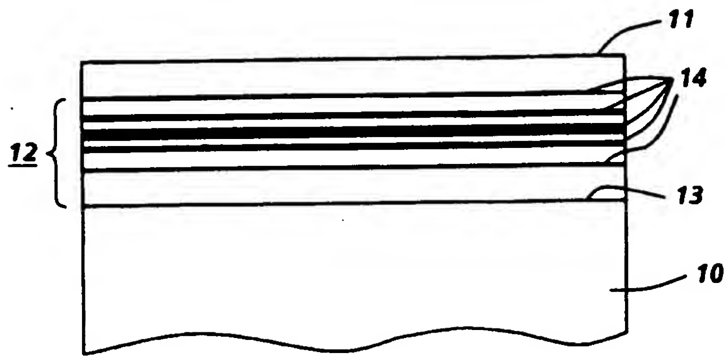

FIG. 1

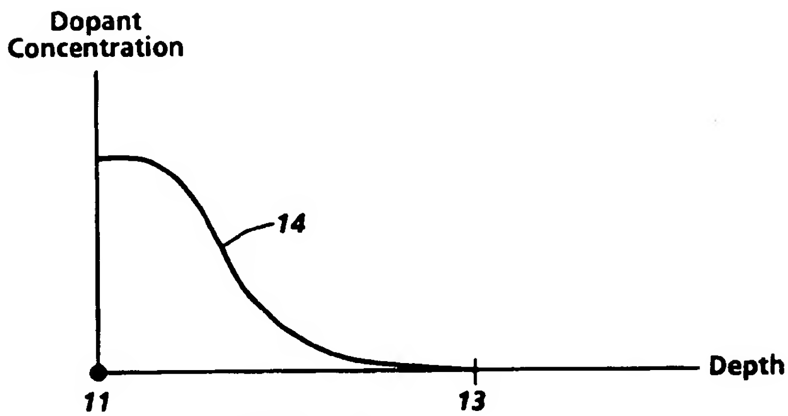

FIG. 2

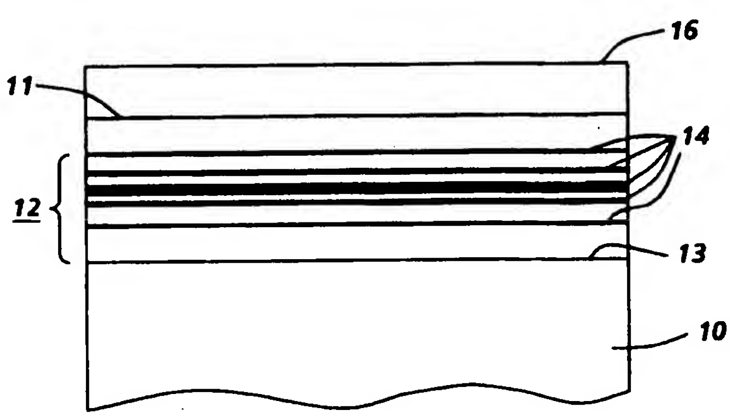

FIG. 3

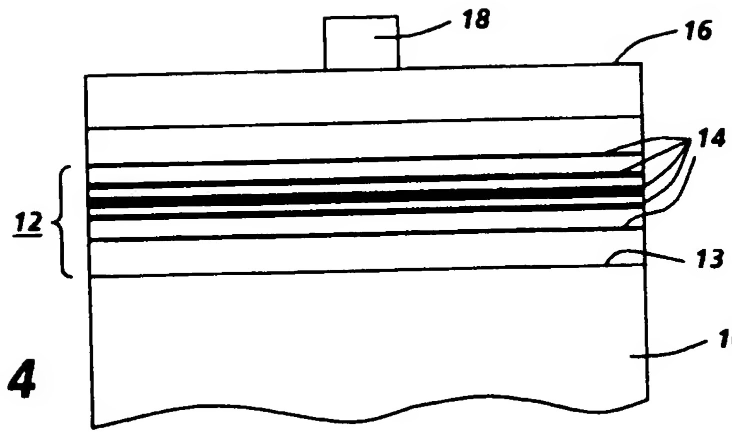

FIG. 4

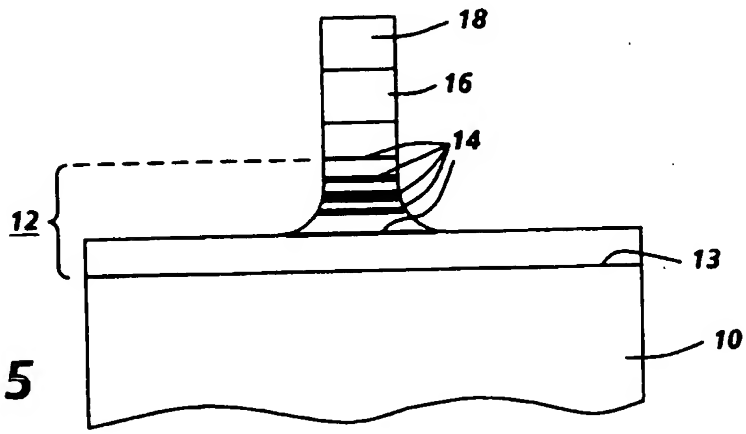

FIG. 5

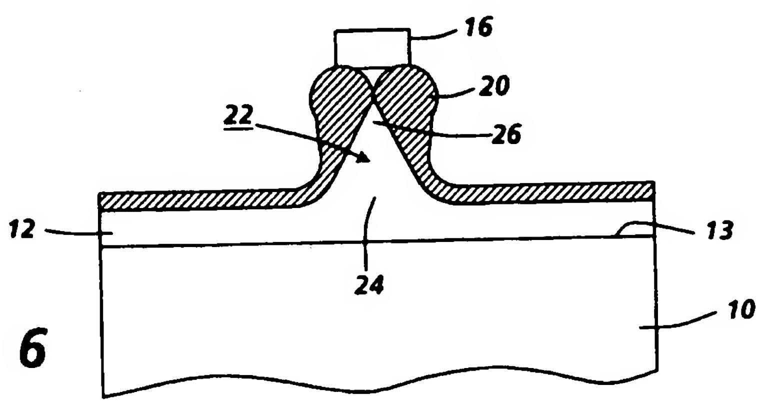

FIG. 6

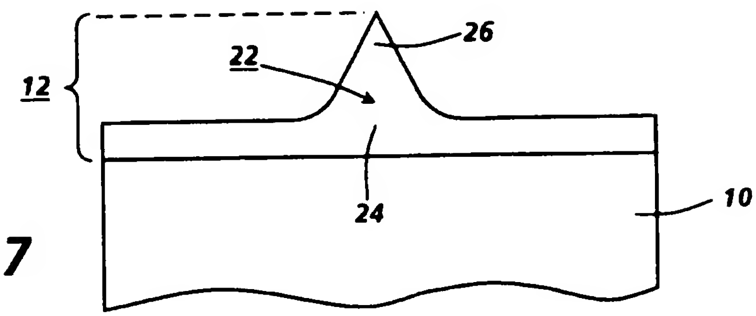

FIG. 7

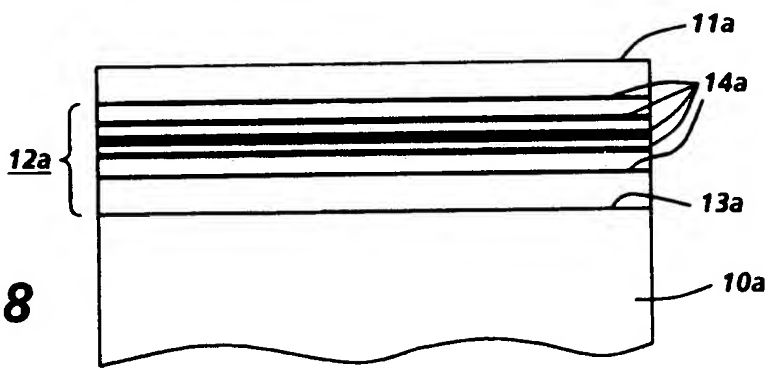

FIG. 8

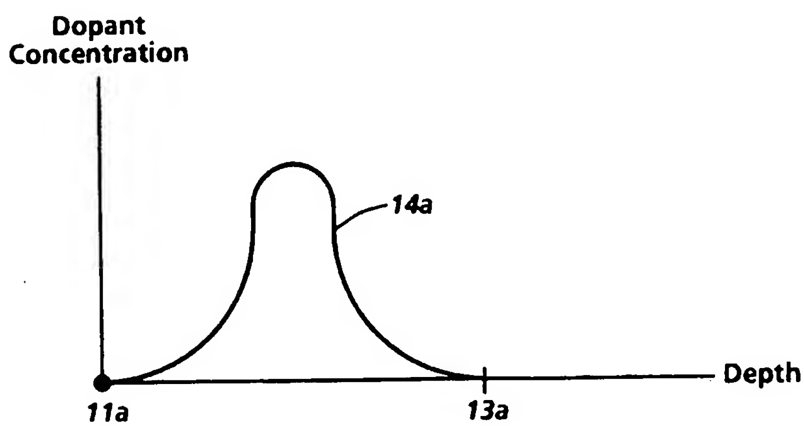

FIG. 9

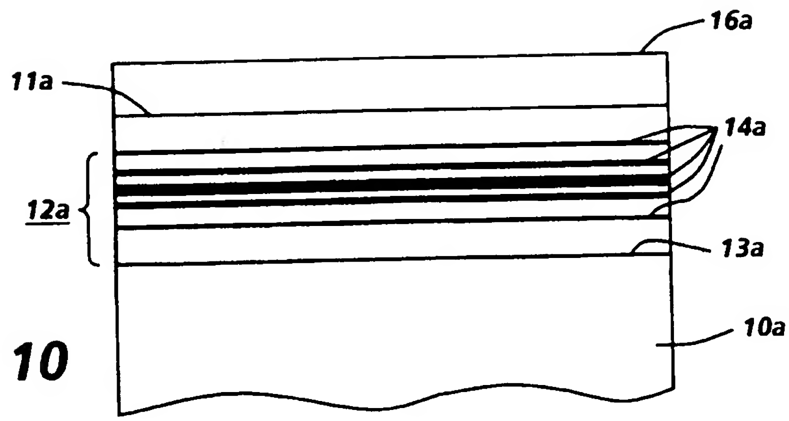

FIG. 10

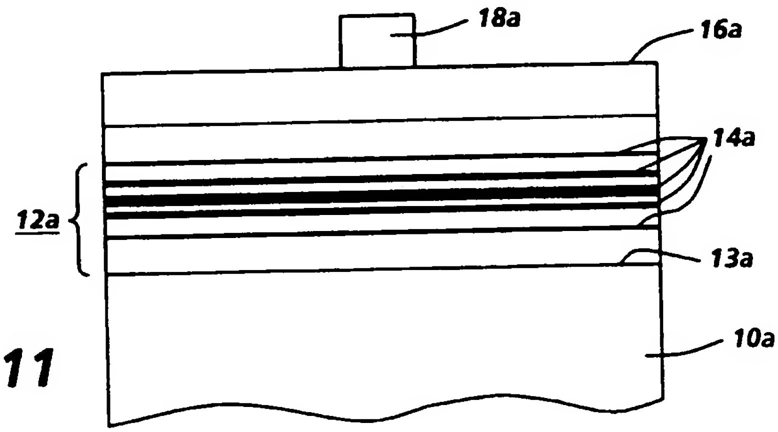

FIG. 11

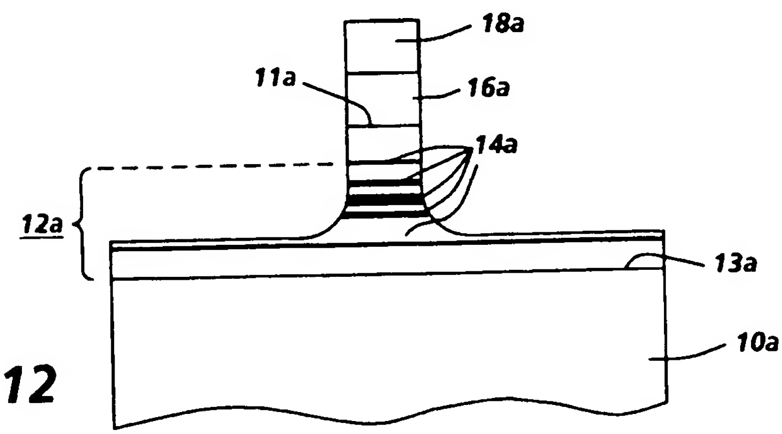

FIG. 12

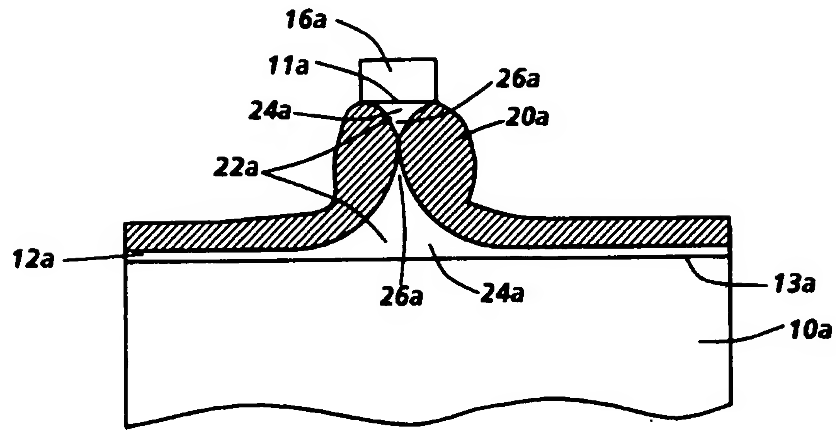

FIG. 13

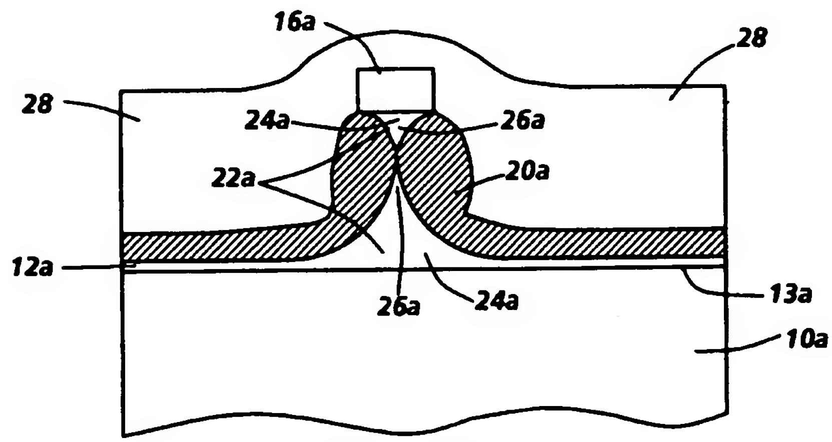

FIG. 14

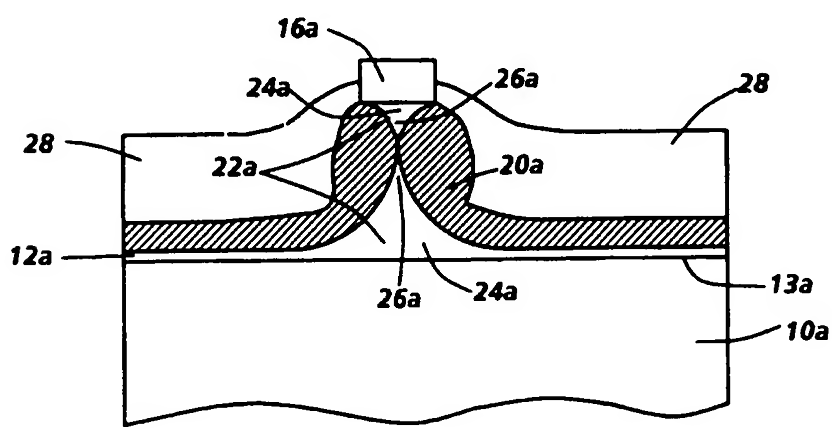

FIG. 15

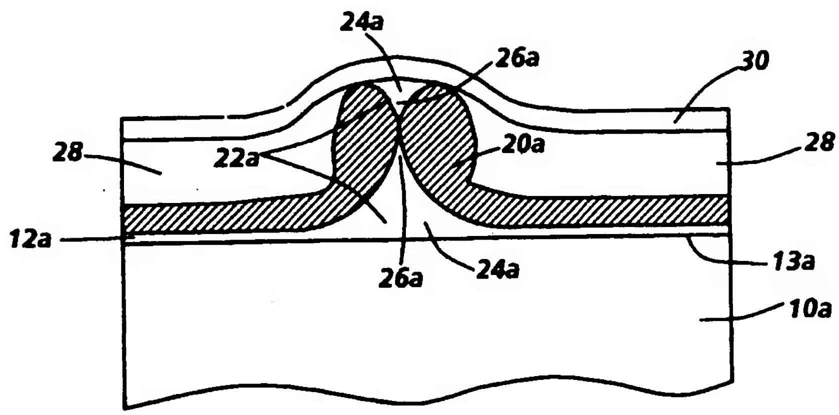
24a
26a
30
28
22a
20a
28
12a
13a
26a
24a
10a

FIG. 16

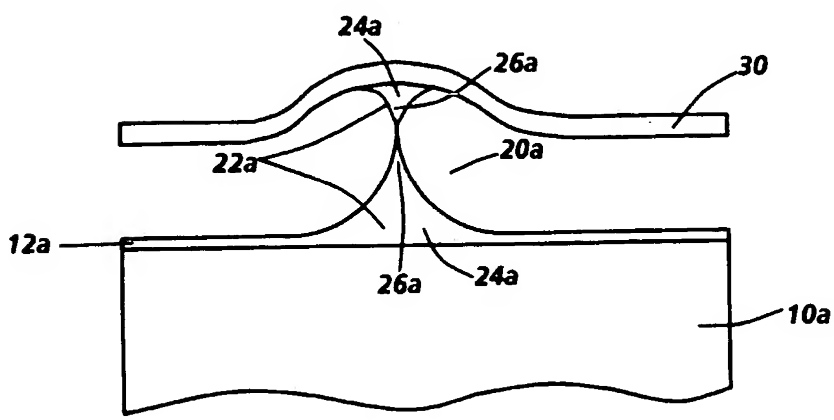
24a
26a
30
22a
20a
12a
26a
24a
10a

FIG. 17

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 93 30 5103

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
D,A	US-A-4 375 643 (K.W.YEH ET AL.) * Abstract * * figures 1-4 * * claim 1 * ---	1,6	H01J9/02
A	IEEE TRANSACTIONS ON ELECTRON DEVICES vol. 38, no. 10, October 1991, NEW YORK pages 2389 - 2391 N.E.MCGRUER ET AL. 'Oxidation-sharpened gated field emitter array process' * the whole document * ---	1,2,6	
A	APPLIED PHYSICS LETTERS vol. 58, no. 10, 11 March 1991, NEW YORK pages 1042 - 1043 D.LIU ET AL. 'Fabrication of wedge-shaped silicon field emitters with nm-scale radii' * the whole document * -----	1,2,4,6	
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			H01J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	14 OCTOBER 1993	DAMAN M.A.

CATEGORY OF CITED DOCUMENTS

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Y : particularly relevant if combined with another document of the same category
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E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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